Environmental Influences On Diel Calling Behavior In Baleen Whales

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LONG-TERM GOALS

Baleen whales rely on acoustic communication to maintain contact with conspecifics for the purposes of social interactions, breeding, and possibly coordinated feeding activities. Passive acoustic monitoring takes advantage of this communication to detect whale presence. Unlike odontocetes that use echolocation to forage, calling in baleen whales is by no means obligatory; therefore, the absence of call detections does not always imply an absence of whales. To effectively apply passive acoustic monitoring to research and mitigation problems, we require a much better understanding of the social and environmental factors that influence variability in the calling behavior of baleen whales. One of the most prevalent observations in passive acoustic recordings over scales of days to months is diel calling behavior (i.e., higher calling rates by day versus night or vice versa; Stafford et al. 2005, Wiggins et al. 2005, Baumgartner and Fratantoni 2008). Increased calling activity during particular times of the day is frequently hypothesized to be caused by diel vertical migration of prey, but few studies have directly studied this relationship because it is difficult to continuously observe acoustic behavior and environmental conditions (e.g., prey migration) in areas occupied by whales over time scales of days to weeks.

Our long-term goal is to elucidate the environmental factors that influence baleen whale calling behavior. In particular, we are interested in the impact of prey distribution and behavior on calling rates. While moored acoustic recorders can and have been used to collect persistent observations of whale calling behavior over the requisite time scales, few technologies exist to continuously collect environmental data throughout the water column over these same time scales of days to weeks. Autonomous vehicles, particularly ocean gliders, have the ability to continuously profile the water column on station for durations ranging from days to months while carrying relevant oceanographic and passive acoustic recording instrumentation. Moreover, gliders equipped with instrumentation to monitor whale presence in real time are also capable of surveying for whales and stopping when aggregations are found. We have implemented an automated low-frequency detection and classification system (LFDCS) for baleen whale calls (Baumgartner and Mussoline 2011) on glider-installed DMON instruments to allow known calls (e.g., right whale upcall and gunshot, fin whale 20-Hz pulses, humpback whale downsweeps, sei whale low-frequency downsweeps) to be detected, tallied, and transmitted to a shore-based computer via the Iridium satellite communication system in near real-time. With this capability, gliders can be deployed in areas that are difficult to access with

ships (e.g., remote regions or challenging seasons), find whales, and study the environmental factors that influence variability in the whales' calling behavior over time scales of days to weeks.

OBJECTIVES

Our objective is to investigate the relationship between prey behavior and baleen whale calling behavior in a poorly studied environment: the central Gulf of Maine during late fall and early winter. We hypothesize that diel calling patterns are established, in part, by the diel availability of prey: when prey is strongly aggregated during the day at depth, calling activity is reduced while the whales feed. Conversely, during periods of active vertical migration by prey or when prey is diffusely distributed, the whales cannot profitably forage, and therefore increase calling activity and social interactions in lieu of feeding. To address this hypothesis, we will (1) deploy ocean gliders to locate whales and simultaneously observe prey migration behavior and whale acoustic activity, and (2) conduct shipboard zooplankton sampling in the region to identify available prey, including both migrating and non-migrating species.

APPROACH

We deployed two gliders on November 12, 2012 just west of Jordan Basin in the northern Gulf of Maine, and the gliders remained at sea for 3 weeks (Figure 1a). Each glider was equipped with sensors to measure temperature, salinity, chlorophyll fluorescence, and optical backscatter, and one of the gliders carried a 1 MHz acoustic Doppler current profiler to measure acoustic backscatter. Additionally, each glider was equipped with a DMON/LFDCS to passively record baleen whale calls and to process the acoustic data in real-time to detect, classify, and report whale calls to a shore-based computer system via Iridium satellite communications. One of the gliders was deployed in station-keeping mode to examine temporal variability in calling behavior and environmental properties, while the second glider was used to do an acoustic survey inside our 40×60 km study area. The survey glider profiled continuously from the surface to just above the sea floor to collect full water column profiles of physical and biological oceanographic properties (e.g., temperature, salinity, chlorophyll fluorescence). The station-keeping glider unfortunately developed an apparent leak in the hull early in the study, and was restricted to profiling between the surface and 50 m depth.

We also did a 9-day cruise to the study area aboard the R/V *Endeavor* from November 29 to December 4, 2012 to conduct intensive environmental and prey sampling in proximity to the gliders. This sampling will (1) allow us to identify both migrating and non-migrating prey in the region so that we can evaluate behaviors in the context of the ecology and life history of each prey species, and (2) provide in-situ observations of species-specific prey abundance to corroborate the 1-MHz ADCP measurements collected by the gliders. In addition to collecting passive acoustic observations collocated with oceanographic measurements, the glider survey design was also designed to locate whales in the region to facilitate proximate sampling from the R/V *Endeavor*. As expected for the time of year, periods of low winds and calm seas were infrequent and short (Figure 1b), making traditional shipboard marine mammal observations difficult. The real time detection data from the gliders were intended to aid in our finding whales quickly once on location aboard the R/V *Endeavor*. To our knowledge, *this was the first use of real-time detection and reporting of marine mammal calls from autonomous underwater vehicles to adaptively plan research activities*.

Once on scene with whales, we collected depth-stratified zooplankton samples with a 1-m^2 multiple opening-closing net and environmental sensing system (MOCNESS) capable of catching zooplankton ranging in size from small copepods (e.g., *Oithona* spp.) to large euphausiids (e.g., *Meganyctiphanes norvegica*). Sampling occurred during both day and night to assess diel changes in species-specific vertical distribution. We also profiled with an instrument package consisting of a conductivity-temperature-depth profiler, chlorophyll fluorometer, optical plankton counter (OPC), and video plankton recorder (VPR). The net, OPC, and VPR data are being used to examine prey behavior and to identify the dominant zooplankton species in the region.

WORK COMPLETED

Final DMON/LFDCS preparation occurred in October and early November, and the gliders were deployed successfully on November 12, 2012 from the R/V *Gulf Challenger*. Real-time detection data were posted to the website dcs.whoi.edu immediately upon receipt from the glider, so we could plan survey activities on the R/V *Endeavor* (the real-time data are now archived at dcs.whoi.edu). The gliders surveyed for 2 weeks before being joined by the science crew on the R/V *Endeavor*. Because of the availability of the real-time detection data, we encountered right whales within 3 hours of beginning our search on the first survey day when sea conditions calmed to Beaufort 6 or less (November 30). We conducted visual surveys in proximity to the gliders to validate the real-time detections, and we sampled in proximity to whales using both the MOCNESS and the vertical profiling instrument package. We recovered both gliders from the R/V *Endeavor* on December 4, 2012.

Post-cruise analysis of the real-time detections and acoustic data from the DMON resulted in a publication (Baumgartner et al. 2013), and an oral presentation of this work was given at the following conferences:

- 6_{th} International Workshop on Detection, Classification, Localization, and Density Estimation (DCLDE) of Marine Mammals using Passive Acoustics held June 12-15, 2013 at the University of St Andrews, Scotland.
- North Atlantic Right Whale Consortium Meeting held November 6-7, 2013 in New Bedford, Massachusetts
- 17^{th} Biennial Ocean Sciences Meeting held February 23-28, 2014 in Honolulu, Hawaii.
- 2^{nd} International Conference and Exhibition on Underwater Acoustics held June 23-27, 2014 in Rhodes, Greece.
- 168^{th} Meeting of the Acoustical Society of America held October 27-31, 2014 in Indianapolis, Indiana
- WHOI-NEFSC Special Seminar Series on Fisheries and Ecosystem Acoustics on February 11, 2015 in Woods Hole, Massachusetts
- Watkins Memorial Marine Mammal Bioacoustics Symposium held March 27-19 in New Bedford, Massachusetts

Analysis of the zooplankton data collected with the MOCNESS and the vertical profiling instrument package was completed, and anlaysis of the entire acoustic, sighting, and zooplankton datasets is ongoing. A manuscript is now in preparation describing the science results of the project.

RESULTS

During the 3-week deployment, the two gliders reported over 25,000 acoustic detections attributed to fin, humpback, sei, and North Atlantic right whales. Real-time detections were evaluated after recovery of the gliders by (1) comparing the acoustic detections to continuous archived audio recorded by the DMON, and (2) comparing species-specific detection locations with nearby sightings collected from both an aircraft and ship. The overall false detection rate for individual calls was 14%, and for right, humpback, and fin whales, false predictions of occurrence during 15-minute reporting periods were 5% or less. Transmitted pitch tracks, compact representations of sounds, allowed unambiguous identification of both humpback and fin whale song in real time. In 10 cases when whales were sighted during concurrent aerial or shipboard surveys and a glider was nearby (within 20 km and ±12 hours), 9 of those sightings were accompanied by real-time acoustic detections of the same species by the glider. These results are reported in detail in Baumgartner et al. (2013).

Acoustic detections in the Outer Fall were significantly reduced in 2012 when compared to acoustic detections of baleen whales obtained during a similar glider deployment in the Outer Fall during late fall 2009. Visual sightings from the NOAA NEFSC aerial surveys were also significantly lower in 2012 than in 2009 for right, fin, and sei whales. This change in occurrence was strongly linked to dramatic warming of the entire water column in 2012 compared to 2009, which in turn, likely had a strong affect on zooplankton and fish abundance. From our shipboard sampling in 2012, zooplankton abundance was quite low in the study area and well below what would be considered sufficient for feeding right whales. The reduced abundance of both prey and baleen whales in 2012 made study of the factors that influence diel patterns in calling behavior difficult. There was no observed diel vertical migration of late-stage *C. finmarchicus*, the primary prey of right whales, and there was little evidence of coherent vertical migration of euphausiids (although again, abundances of these zooplankton was quite low). Interestingly, right whales exhibited the same diel calling patterns in 2009 and 2012, suggesting that at least the abundance of prey had little influence on calling behavior.

IMPACT/APPLICATIONS

This project demonstrates a number of capabilities developed over the past several years with ONR support, including (1) the capacity for gliders to persistently study marine mammals in remote or harsh environments in which traditional shipboard studies are quite difficult, (2) on-board detection, classification, and reporting of low-frequency baleen whale calls from autonomous underwater vehicles in near real-time using the DMON/LFDCS, and (3) the use of these real-time detection reports to direct ships to areas populated with whales. The LFDCS is designed to be extremely flexible such that adding new call types is trivial. In addition to the species listed above, the calls of blue whales, bowhead whales, bearded seals, and ribbon seals have also been included in the LFDCS call library. Although our project focuses on the Gulf of Maine, we anticipate that these capabilities will be extremely useful in other areas for not only ecological research, but for mitigation applications as well.

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PUBLICATIONS

Baumgartner, M.F., D.M. Fratantoni, T.P. Hurst, M.W. Brown, T.V.N. Cole, S.M. Van Parijs, and M. Johnson. 2013. Real-time reporting of baleen whale passive acoustic detections from ocean gliders. Journal of the Acoustical Society of America 134:1814-1823. [published, refereed]

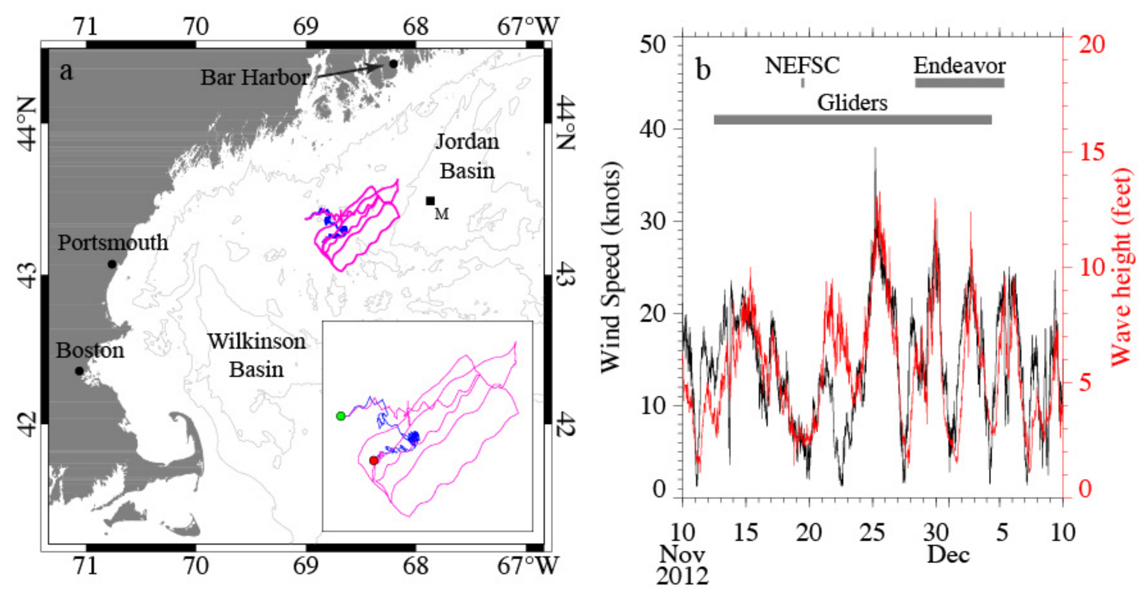

Figure 1. (a) Tracks of gliders we08 (blue) and we10 (magenta) in the Outer Fall region of the central Gulf of Maine. Northeast Regional Association of Coastal and Ocean Observing Systems (NERACOOS) buoy M shown as a filled black square. Inset shows deployment (filled green circle) and recovery (filled red circle) locations. (b) Wind speed (black) and wave height (red) at NERACOOS buoy M during the study period. Gray bars indicate times of glider deployments, R/V **Endeavor** ***cruise, and Northeast Fisheries Science Center (NEFSC) aerial survey.***